

APPLICATION FOR UNITED STATES LETTERS PATENT

FOR

SUBSTRATE CONFINEMENT APPARATUS AND METHOD

Inventors:

Alexander Starikov
Laura Oliphant

Intel Corporation

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Schwabe, Williamson & Wyatt, P.C.

Pacwest Center, Suites 1600-1900

1211 SW Fifth Avenue

Portland, Oregon 97204-3795

Phone: 503-222-9981

Express Mail Label No.: EV370165778US

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SUBSTRATE CONFINEMENT APPARATUS AND METHOD

Field of the Invention

[0001] Disclosed embodiments of the invention relate to the field of substrate processing, and more particularly, embodiments of the invention relate to constraining a substrate in specified coordinates during processing, such as for substrate chucking at lithography.

Brief Description of the Drawings

[0002] The invention is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings, in which the like references indicate similar elements and in which:

[0003] **FIG. 1** illustrates a cross-sectional view of a substrate confinement apparatus in accordance with an embodiment of the present invention;

[0004] **FIG. 2** illustrates top view of a substrate confinement apparatus and substrate in accordance with an embodiment of the present invention;

[0005] **FIG. 3.** Illustrates a cross-sectional view of a substrate confinement apparatus in accordance with an embodiment of the present invention; and

[0006] **FIG. 4** illustrates a process for confining and unconfining a substrate in accordance with an embodiment of the present invention.

Detailed Description of Embodiments of the Invention

[0007] In the following detailed description, reference is made to the accompanying drawings which form a part hereof wherein like numerals designate like parts throughout, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. Therefore, the following detailed description is not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

[0008] Embodiments in accordance with the present invention provide a substrate confinement apparatus and a substrate confinement method that may assist in the confinement of a substrate, such as a silicone wafer, in fixed coordinates with respect to a confinement apparatus, despite the forces that are imposed on a substrate as it is being processed or transferred from one process to another. One or more substrate retainers in accordance with the present invention may be used to improve control of the top surface, such as planarity, despite local imperfections on a substrate back side or on the substrate chuck.

[0009] Current substrate confinement apparatuses are often referred to as "wafer chucks", which typically may confine a substrate in different ways. One such example is known as a contactless chuck, where a plurality of air jets and vacuum ports may be used to maintain the substrate in a substantially planar position and achieve lateral (X, Y and potentially Θ) in plane confinement through mechanical contact and the substrate side. Another wafer chuck is a low contact area chuck, which confines a

substrate with direct contact of a large vacuum operated seal positioned about the outer periphery of the substrate with several inner hard supports positioned within the perimeter of the seal for supporting the interior portion of the substrate. Other higher area contact chucks may also be used.

[0010] Contactless chucks allow more in-plane movement that is desired, as there may be some tolerance between the mechanical contact with the substrate sides. Contact chucks, on the other hand, constrain the substrate on a very small lateral spatial scale, such that the substrate cannot properly relax into a chucked position conformal with the surface of hard contact. Additionally, contact surface particulate contamination and wear can cause out of plane confinement and impact processing side planarity. In one embodiment in accordance with the present invention a wafer may be constrained in-plane, such that lateral movement in either the X, Y or rotational Θ is restricted with minimal substrate contact, allows the substrate to properly relax into a chucked position. And though some contact is made, it can accommodate certain wear and/or contamination issues and maintain global planarity of the process side of the substrate.

[0011] **FIG. 1** illustrates a cross-sectional view of a substrate confinement apparatus in accordance with an embodiment of the present invention. A Substrate 10, which may be for example a silicon wafer, is in a position for processing of the process side 12 of substrate 10. As shown, the wafer may be fully confined and also said to be in the "chucked state." Examples of processing stages where the substrate may need to be in the chucked state include, but are not limited to, lithography, chemical mechanical polishing (CMP), inspection and metrology and transfer/transport.

Accordingly, in these and other processes it may be necessary that process side 12 of substrate 10 to remain globally planar and in fixed coordinates so it does not move in certain directions, but may allow for local independent movement of portions of the back side, depending on situations such as back side imperfections, particulate contamination, chuck irregularities and the like.

[0012] As shown, substrate 10 may be constrained in-plane and restrained in one or more degrees of lateral movement. Substrate 10 may be so confined by at least one or more substrate retainers 20 in accordance with embodiments of the present invention. Thus, when movement within a plane is to be restricted (e.g. lateral movement) three degrees of substrate movement that may be resisted by the substrate retainer 20 includes movement along the X and Y axes and movement in the rotational Θ direction, shown by the coordinate legend 8.

[0013] Substrate retainer 20 may include a retainer body 22 and flexure 30, and when coupled to the substrate back side 14, may allow for local out of plane substrate movement in the vertical Z direction, while confining in plane lateral movement.

Absence of hard local confinement in the Z direction may be necessary during certain processes, such as lithography, to enable the substrate being processed to appropriately relax into a globally planar confined state. In cases, such as CMP, such Z movement may be needed for uniform back side pressure, or locally spatially modulated back side pressure as may be required for CMP material removal of a process side so it can be processed into a planar surface.

[0014] Substrate 10 may be substantially confined to a single plane through the use of a global confinement system such as a pressure control system using alternating

vacuum ports 16 and air jets 18 or an electrostatic control system, or some other known form of confinement. The vacuum ports 16 and air jets 18 work in conjunction with one another providing sufficient upflow and downflow, such that the substrate 10 may be held in-plane without having significant out of plane warp or movement of substrate 10 in the Z direction to maintain control of the process side 12 of substrate 10.

[0015] The alternating vacuum ports 16 and air jets 18 alone, however, do not restrict movement in the X, Y or Θ directions. In typical contactless chucks, some form of mechanical interface is required with the edges of the substrate to restrain X and Y and Θ movement. However, the mechanical interface allows for some movement, as some tolerance must exist between the substrate edge and the mechanical interface, otherwise, the substrate cannot float and move, if necessary, in the Z direction.

[0016] In an embodiment in accordance with the present invention, retainer 20 may be used to restrain in-plane movement of substrate 10 and maintain the X, Y and Θ coordinates, as well as allow for local independent movement in the Z direction. Retainer 20 may include a retainer body 22 that has a contact surface 24 configured to removably couple with substrate back side 14. Retainer body 22 and contact surface 24 may removably couple to substrate back side 14 through the use of a vacuum and/or suction effect. A number of other techniques may be used to interconnect retainer body 22 and contact surface 24 to the substrate back side 14, including, but not limited to, electrostatic forces, VanderWaals force, magnetic forces, and meniscus and capillary forces where an interface material may be used.

[0017] Retainer body 22 may be coupled to a flexure 30. Flexure 30 may be a stiff membrane, and may be designed to allow unhampered motion in one or more

directions, but is extremely inflexible in other directions. Thus, for example, where movement is only desired in the Z direction, as shown by position 32 for example, flexure 30 may be designed to restrict lateral movement in the X and/or Y directions, as well as restrict rotational movement in the Θ direction. Flexure 30 may then allow freedom of movement in the Z direction, as shown by flexure position 32.

[0018] The coupling of the retainer body 22 to the flexure 30 may be through a variety of ways, including, but not limited to, a mechanical interconnection, such as a rivet, screw, or welding, and/or a chemical/mechanical interconnection, such as an adhesive. In an other embodiment, the retainer body and the flexure may be made out the same material as a unit.

[0019] Under ideal conditions, there would likely be little or no need for the substrate 10 to move in the Z direction. However, due to a variety of reasons, including, but not limited to, substrate back side imperfections, processing irregularities and the presence of contaminants, portions of the substrate back side 14 may need to be allowed out of plane on back side 14, which may require locally allowing limited Z movement, to improve planarity of the process side 12, and globally confining the overall Z movement of the front side, while constraining the in-plane degrees of freedom.

[0020] Substrate retainer 20 achieves such a result, in that it may allow local Z movement as required for global planarity of the process side 12 and restrain movement out of the X, Y or Θ coordinates, which may be coordinates that need to be maintained throughout the process. It can be appreciated however, that other coordinates may also be constrained, as needed, including the Z coordinate, such that the flexure allows

movement in another direction, depending on the process and substrate being processed. This may be accomplished by selecting a flexure and material that meets such movement controlling parameters.

[0021] Suitable materials for flexure 30 may include metal-based materials, such as steel, aluminum, and other alloys, as well as non-metal-based materials, such as glass, quartz, synthetic diamond, sapphire, and the like. The flexure may also be configured or supported in several ways, including, but not limited to single sheet having two points of attachment.

[0022] As illustrated in **FIG. 1**, two substrate retainers 20 may be coupled to the substrate back side 14. In such a case, each retainer body 22 may be coupled to a corresponding flexure 30 and 30' respectively, which may be configured to restrain lateral movement. Either substrate retainer may constrain X movement and the other constrain Y movement. The substrate retainers 20 may be positioned at different points away from the center of the substrate 10, and together may operate to constrain rotational movement or the Θ coordinate. The two substrate retainers may be configured to independently allow movement in the Z direction such that the substrate may properly settle into a chucked state and control the planarity of the process side 14, while allowing for back side irregularities, such as substrate back side 12 imperfections.

[0023] **FIG. 2** illustrates a top view of a substrate and substrate confinement apparatus in accordance with an embodiment of the present invention. Three substrate retainers may be horizontally spaced apart from each other in a generally equilateral relation fashion. Similar to a tripod, this configuration may provide sufficient support at enough points on the substrate back side to provide a substantially uniform support of

the substrate 10 for it to be lowered into the plane of confinement or lifted from the plane of confinement. The three substrate retainers 20 may also provide substantial lateral confinement, restricting several degrees of freedom, including X, Y and Θ . As with the embodiment where two substrate retainers are used, each substrate retainer may allow for local Z movement, but overall global confinement may be sufficiently constrained by the global confinement system, such as alternating air jets and vacuum ports.

[0024] In other embodiments, more than three substrate retainers may be used to allow certain degrees of freedom and restrict others. The more contact points made with the substrate back side, however, may create additional problems that are undesirable in certain applications, including, but not limited to the problem of the substrate to not properly relax into a fully constrained position as is the case in the currently used contact and low contact area chucks. In other cases, having redundant substrate retainers can be a benefit, such as when a back side surface does not uniformly enable effective attachment, or where independent operation of back side retainers may be used to assure failure free operation, even where one retainer fails to attach due to particulate surface contamination. Redundant arrays of substrate retainers may also avoid atomic or ionic cross contamination of processes, such that - where one sub-set of substrate retainers have contacted a copper bearing substrate, for example, if a non-copper bearing substrate were to be run in the same machine, the other redundant sub-set of substrate retainers may be used to avoid cross contamination and maximize machine usage.

[0025] In another embodiment, if positioned in the center of the substrate, a single substrate retainer 20 may be used to restrict at least one or more degrees of movement. However, given the potential forces encountered by the substrate that may be translated to the substrate retainer, and the potential size difference between the substrate being processed and the retainer contact surface 24, multiple retainer bodies may better restrict certain degrees of movement.

[0026] Whether using a single or multiple substrate retainers, the substrate retainers may be carried by a stage that coordinates the movement of the substrate retainers with other elements of a substrate chuck.

[0027] A problem that may arise, particularly when processing ultra-thin substrates, is potential for dimpling. Dimpling may be inward toward the retainer body, such as may result when a suction/vacuum connection is made, or outward creating a bump in the process side where other attractive forces are used. Dimpling may be caused by the interface between the contact surface and the substrate back side in conjunction with the forces being exerted.

[0028] Accordingly, referring to **FIG. 1**, when vacuum is used, for example, to secure the substrate retainer 20 to the substrate back side 14, using a smaller diameter contact surface 24 and reducing the inner diameter of the aperture 26 may help resist the inward dimpling effect, which in turn may cause the process side 12 of substrate 10 to be more unaffected by any back side interconnection. In the alternative, or in addition to, the number of substrate retainers may be increased to gain in-plane friction with out dimpling over individual substrate retainers. Though not required, it has been found that a diameter for aperture 26 may be approximately 2 mm without resulting in

significant dimpling on substrates that are on the order of approximately 0.5 mm in thickness. It can be appreciated, however, that the thinner the substrate, the inner diameter may be reduced to avoid dimpling effects.

[0029] Likewise, if a different method to removably couple the retainer body to the substrate back side 14 is used, such as electrostatic force, a contact surface diameter that is too small may increase the outward dimpling effect. It may therefore be necessary, depending on the coupling method used, to adjust the contact diameter of the retainer body to resist dimpling by either decreasing or increasing the diameter of the retainer bodies as necessary.

[0030] Another problem that may occur is the eventual wear of the contact surface, due to its contact with a substrate back side. Wear on the contact surface may hamper the ability of retainer to securely couple to the substrate back side. Uneven wear among multiple retainer contact surfaces may cause the substrate to not be properly confined to particular coordinates. Although contact surface wear, even non-uniform wear, may be tolerated by substrate retainer embodiments in accordance with the present invention, as the flexure movement may compensate for surface wear, to help avoid such wear, for example, a hard surfacing material may be applied to the contact surface, or, the retainer body be made of a solid hard material. Such hard facing materials may include, but are not limited to, diamond facing or carbide coating. Additionally, redundant substrate retainers may be included in the substrate chuck such that depending on the process, fewer or more than three retainers may be used. Or, if a substrate retainer contact surface is worn, a redundant substrate retainer may be used while the worn retainer is replaced.

[0031] **FIG. 3** illustrates a cross-section of a substrate confinement apparatus in accordance with an embodiment of the present invention. As shown, an actuator 40 may be used to facilitate the chucking or dechucking of a substrate 10. Actuator 40 may raise to support the flexure 30 and retainer body 22 in an up/receiving position when substrate 10 is brought into position for processing. The support provided by actuator 40 may allow retainer body 22 to couple or decouple to the substrate back side 14.

[0032] Actuator 40 can supply the necessary coupling medium to the retainer body to enable coupling to the substrate back side, such as a vacuum or electrostatic force. For example, actuator 40 can act to provide the necessary vacuum to retainer body 22 to enable coupling to the substrate back side 14, if vacuum and suction is the method of coupling. Actuator 40 may also relieve the pressure to break the vacuum is decoupling is desired. Once coupled or decoupled, the actuator 40 may then retract (as seen in **FIG. 1**) to allow the substrate to settle into the position dictated by the global Z confinement, such as the alternating air jets 18 and vacuum ports 16.

[0033] Embodiments in accordance with the present invention may be suitable for application in lithography and may be used in conjunction with contactless chucks to enable lateral in-plane confinement, as well as enable a higher degree of substrate conformance to the surface of the contactless chuck. Embodiments in accordance with the present invention may also be suitable for substrate confinement in Chemical Mechanical Polish (CMP) processes to enable better control of substrate back side pressure and accommodate substrate back side surface imperfections.

[0034] Embodiments in accordance with the present invention may also be suitable for substrate confinement where translation in one or more axis or degrees of freedom may be allowed or required, such as in precision positioning devices like Flexure Stages. Embodiments in accordance with the present invention may also be suitable for substrate confinement in contactless transfer arms and end-effectors. Embodiments in accordance with the present invention may also be suitable for substrate confinement for back side contactless substrate transport devices where a substrate is riding from one point in space to another and is constrained in plane so as to not come into hard contact with the walls of the substrate transporter.

[0035] Substrate confinement in lithography may tend to attain a desired global planarity, with the tightest restriction on substrate movement. Whereas, in CMP, some degree of substrate movement may be tolerable, and in transport/transfer operations may be even more so. Excessive lateral movement, however, in general is undesirable in many processes.

[0036] Another embodiment of the present invention may include a flexible back side constraint for substrates in a substrate carrier that may have limited back side only contact, which may allow for considerable flexibility and independent travel to absorb the forces encountered, but maintains the substrate in a confined state and precludes hard contact with the stage or carrier of the substrate and substrate retainers.

[0037] **FIG. 4** illustrates a process for chucking and dechucking a substrate in accordance with an embodiment of the present invention. A substrate confinement apparatus is provided having at least one substrate retainer in accordance with an embodiment of the present invention (100). A Substrate may be positioned in the

substrate confinement apparatus for processing (110). This can be done in a number of ways, including but not limited to an end-effector bringing the substrate to the confinement apparatus. An actuator may be used to urge the flexure and retainer body toward the substrate, and thereby urge a contact surface of the retainer body into contact with the substrate back side (120). The retainer body may be coupled to the substrate back side (130). This coupling may be through number of coupling forces, such as vacuum/suction applied through the actuator. The actuator may be retracted from the flexure and retainer, thereby leaving the retainer coupled to the substrate back side and allow substrate and substrate retainer to settle into a neutral state (140). The global confinement system may be activated to maintain the substrate in a substantially planar position (150). In one embodiment the global confinement system may include a plurality of alternating air jets and vacuum ports. Once confined in plane and restricted from lateral in plane movement, the substrate is ready for processing. To de-chuck the wafer, a reverse of the above process may be used.

[0038] Although specific embodiments have been illustrated and described herein for purposes of description of the preferred embodiment, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations calculated to achieve the same purposes may be substituted for the specific embodiment shown and described without departing from the scope of the present invention. Those with skill in the art will readily appreciate that the present invention may be implemented in a very wide variety of embodiments. This application is intended to cover any adaptations or variations of the embodiments discussed herein.

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Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.